3.2.4. MONITORING AEROSOL OPTICAL DEPTH

BRW and SPO

Background. Atmospheric aerosols affect the Earth's radiation budget directly through interactions with solar and terrestrial radiation and indirectly as cloud condensation and ice nuclei. While the impact of aerosols is probably most pronounced downwind of midlatitude industrial complexes [e.g., *Charlson et al.*, 1992], high-latitude regions are also sensitive to variations in atmospheric turbidity. This is especially true in the Arctic when airborne pollutants and dust from Eurasia are transported poleward, and whereas aerosols tend to have a cooling effect at low and middle latitudes, their radiative effects are less certain at high latitudes. The effects of high surface albedo in conjunction with low solar angles may cause a warming instead [*Cacciari et al.*, 2000]. The focus of the CMDL aerosol program is to characterize the means, variability, and trends of aerosols regionally. A further goal is to understand the factors that control the distribution of aerosols and their radiative properties.

Need for monitoring. In 1998 the Scientific Committee on Antarctic Research (SCAR) recognized the importance of polar aerosol characterization and recommended the establishment of an international network of solar spectrophotometers to monitor aerosol optical depth (AOD) at high southern latitudes. Such a network now exists, and some participating countries also maintain sites in the Arctic, thus providing a polar perspective. CMDL has monitored aerosol properties at two polar sites (BRW and SPO), since the mid-1970s. An overview of these activities is given by *Stone* [2000] and references therein. Historically, ground-based in situ properties of aerosols were derived with nephelometer measurements [e.g., *Bodhaine*, 1992, 1996]. In recent years a strategy was adopted to relate chemical and physical properties by means of simultaneous size-selective sampling, allowing observed aerosol properties to be correlated with atmospheric cycles of specific chemical species [*Ogren*, 1995]. In addition, CMDL has monitored effective visible (500-nm) aerosol optical depth at BRW and SPO. The derivation utilizes data from pyrheliometers fitted with moderately wideband filters [*Dutton and Christy*, 1992]. While not a precise measure, the long time series have been valuable for the definition of seasonal cycles and for the documentation of episodic perturbations caused by the presence of volcanic aerosols.

Figure 3.18 highlights the extreme increases in visible extinction at polar latitudes, which were caused by the eruptions of El Chichón and Pinatubo in 1983 and 1991, respectively. After major eruptions, volcanic aerosols are dispersed globally by stratospheric winds and then decay exponentially. Over polar regions, however, decay times tend to be longer [*Stone et al.*, 1993, 1994]. The prolonged lifetime of volcanic aerosols at high latitudes may result from unusual processes that occur within the polar vortex. Aerosols may persist if dynamical processes favor vaporization at high altitudes and regeneration of particles at lower altitudes [*Hofmann and Rosen*, 1987]. Also, natural elimination processes may be suppressed because mixing within the polar vortex is minimal. A limited number of

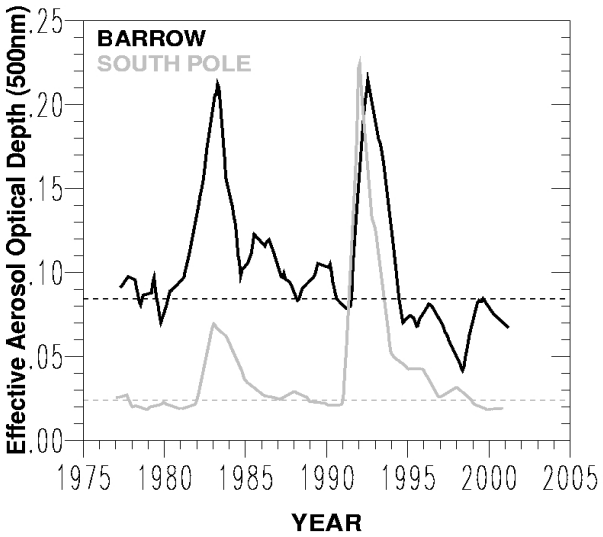

Fig. 3.18. Time series of effective visible aerosol optical depth (AOD) derived from filtered pyrheliometric measurements made at BRW and SPO. Two-year smoothed values are shown to highlight the periods of increased AOD following the eruptions of El Chichón and Pinatubo. The dashed lines represent the long-term average background conditions at each site.

spectral observations of aerosol extinction at BRW were used to derive some understanding of composition and size distributions of volcanic aerosols [*Dutton et al.*, 1984; *Stone et al.*, 1993]; however, quantifying the direct or indirect radiative forcing by volcanic aerosols is not yet possible because continuous observational records are lacking.

On an annual basis, Arctic haze [*Dutton et al.*, 1989] and Asian dust, and occasionally smoke from forest fires, influence the BRW record [*Stone*, 2002]. In recent decades, significant variability in the concentration of haze during spring at BRW has been observed. *Bodhaine and Dutton* [1993] documented a downward trend of Arctic haze during the 1980s when emissions of haze-forming pollutants in Eurasia may have decreased. However, a definitive explanation for the trend has not been given. While emission rates are certain to influence the distribution of haze, changes in atmospheric transport may also be a factor. Atmospheric circulation in this region has undergone significant shifts in recent decades [*Stone*, 1997; *Stone et al.*, 2002]. In the future, closer attention will be given to the role of transport as it affects the evolution of specific aerosol types (i.e., haze, dust, smoke, or volcanic).

At SPO, intrusions of seasalt aerosols are observed when storms reach the high plateau from surrounding oceanic regions [*Bergin et al.*, 1998; *Bodhaine*, 1992]. Although the direct radiative impact of such aerosols can be studied theoretically [e.g., *Cacciari et al.*, 2000], verification of results will require more continuous monitoring of aerosols in conjunction with measurements of the surface radiation budget. The indirect effects of aerosols (i.e., their role in influencing cloud morphology) has yet to be investigated and will also require correlative studies using highly resolved data sets.

New projects. To address the aforementioned needs, CMDL has enhanced its monitoring programs at BRW and SPO to include continuous measurements of spectral AOD during sunlit periods using photometers fitted with narrowband (10-nm) 1-in-diameter interference filters. Because background values of Arctic and Antarctic optical depths are small (see Figure 3.18), the determination of spectral AOD at BRW and SPO requires extraordinary care to produce high-quality data sets. The main features of these new programs include the following:

- Deployment of four-channel, sun-tracking photometers to measure extinction at nominal wavelengths centered at 412, 500, 675, and 862 nm (368, 412, 500, and 865 nm prior to July 2000).
- One-minute acquisition of raw voltages.
- Acquisition of ancillary data to assure data quality.
- Merging of photometric data with station pressure and temperature to account for Rayleigh scattering using the method of *Bodhaine et al.* [1999], and to correct airmass for refraction at low solar angles.
- Thermally controlling instruments to within ±1ºC of established set points to assure filter stability and longevity.
- Merging of daily ozone and NO_2 data to account for absorption by these constituents.
- Performing pre- and post-season calibrations at MLO, with the Langley method, to document and correct for any filter degradation.
- Careful screening of data with an interactive, graphical editor to eliminate cloud contamination, and by reference to independent radiation data.

Preliminary results. Preliminary processing of data from SPO beginning January 2000 and from BRW beginning March 2000 indicates significant contrasts in aerosol concentration as well as in spectral signature. Time series of 1-min-resolved AOD are now being generated for detailed investigations of the direct and indirect radiative forcing of aerosols. In addition, it is possible to characterize varying types of particles, thus providing a basis to parameterize aerosols in climate models. Figure 3.19 shows a time series of spectral AODs and derived Ångström exponents ($\mathring{a}$) during March-April 2000. Values of $\mathring{a}$ are defined by a power law, where AOD $\propto \lambda^{-\mathring{a}}$. In this case, Ångström exponents were derived for the channel pairs labeled in the lower panel. Generally, Ångström exponents are inversely proportional to mean particle size.

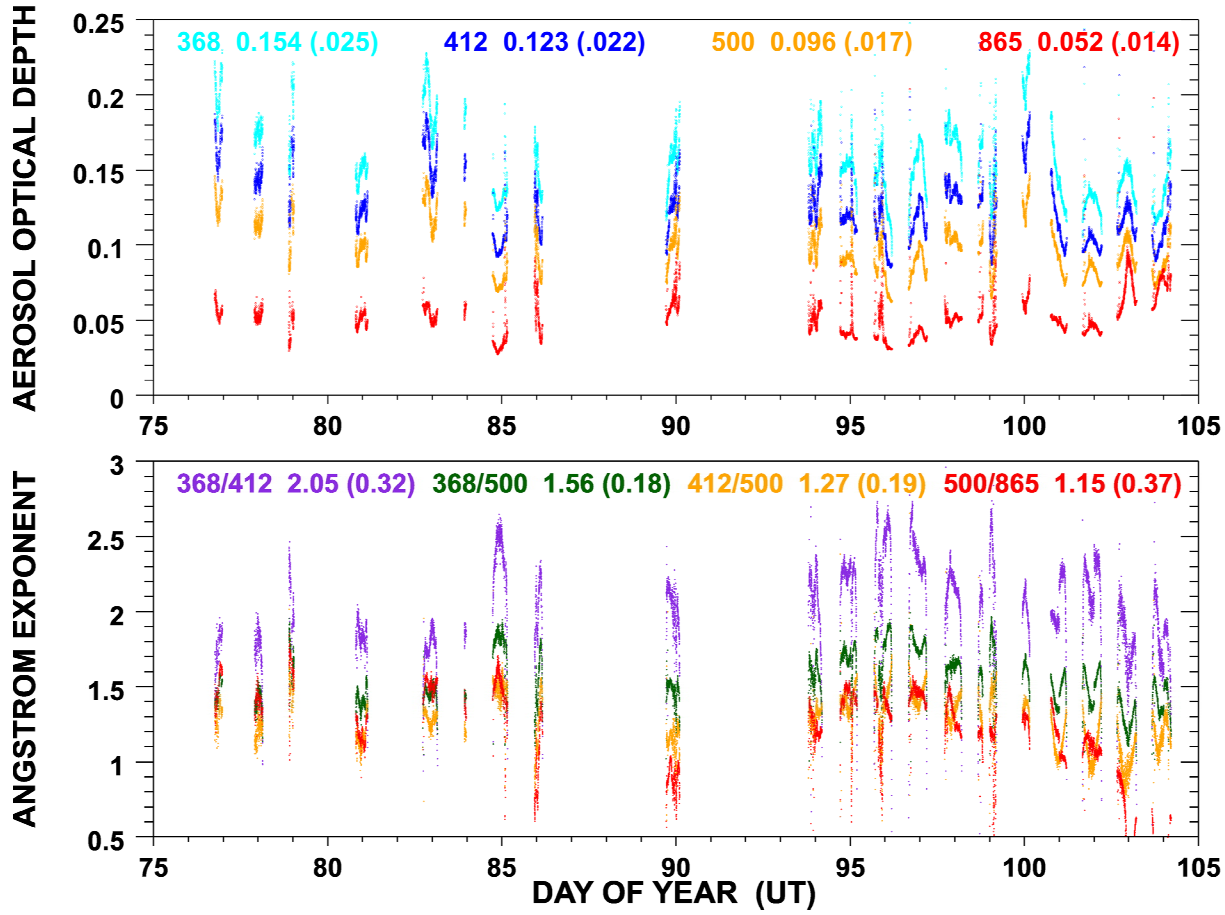

Fig. 3.19. (a) Time series of 1-min spectral aerosol optical depth derived from measurements made with the CMDL SP01-A four-channel sunphotometer at Barrow, Alaska, during March-April 2000, and (b) Ångström exponents, calculated for the channel pairs indicated in the legend. Means and (standard deviations) for the period are also given in the respective legends.

Similar time series from SPO (not shown) reveal less variability. The 500-nm optical depths at SPO are in the range 0.015-0.025, and Ångström exponents are significantly larger than at BRW, indicating the dominance of small particles at SPO.

Previously, the main features of the annual aerosol cycle at the surface at SPO were established with the combination of nephelometer data and derived values of Ångström exponent to infer particle size spectra. Clear signatures distinguish modes of coarse (sodium) and small (sulfur) particles, where peak sodium concentrations are associated with the rapid, poleward transport of seasalt from oceanic regions, principally the Weddell and Ross Seas. *Bergin et al.* [1998] showed how in situ aerosol measurements from South Pole could be correlated with records of chemical species captured in firn samples to study past climate. In the future, correlating surface and columnar properties of aerosols will lead to better interpretation of the firn data in terms of past climate forcing. According to *Bergin et al.* [1998], the possibility exists to resolve, on a seasonal basis, a record of aerosol properties dating from 1000 years ago. Moreover, the natural (e.g., seasalt, biogenic, or volcanic) signatures should be distinguishable from anthropogenic ones.

Goals. The large spatial and temporal differences observed in polar records of aerosols highlight the importance of assimilating similar data from other sites to better characterize polar aerosols spatially and temporally. Initially, efforts should focus on establishment of "background" values of AOD in both polar regions, from which future perturbations, whether from volcanic activity, anthropogenic factors, or other factors, can be referenced. As evidenced in Figure 3.18, the high latitudes are currently experiencing a period of volcanic quiescence; no major eruptions have occurred in recent years, and AOD values are below historical minima (dashed lines indicate the long-term background). Therefore, the opportunity to establish baseline values of spectral AOD and derived properties, such as size spectra [e.g., *King et al.*, 1978], now exists. Once natural seasonal variations are understood over broad spatial scales, climate forcing by polar aerosols can be assessed with greater confidence. Only through international cooperation can adequate information be provided to modelers challenged to improve aerosol parameterizations as called for by the Intergovernmental Panel on Climate Change (IPCC) [*Houghton et al.*, 2001]. Also, the remote sensing community will benefit from these efforts because valid retrievals of surface and atmospheric properties require that accurate corrections be made to account for extinction by aerosol particles in the atmosphere.

Steps have been taken by researchers from several countries to coordinate their polar activities in this regard. Participating countries include Italy, Australia, Germany, Japan, United States, Russia, England, and France. Although a variety of photometers have been used and the data records are of variable length and continuity, there is agreement that an archive of polar AOD data will provide the basis for better characterization of polar aerosols spatially and temporally. Once these data are assimilated, analyses in conjunction with model studies should provide the means to more accurately quantify the peculiar radiative effects of aerosols at high latitudes. The immediate objective of this group is to convene a workshop to set goals for future collaborations and to establish such an archive that may be modeled after the Baseline Surface Radiation Network protocols [*Ohmura et al.*, 1998].

Bermuda, BAO, Boulder, and Kwajalein

Routine monitoring of aerosol optical depth continued at Bermuda, BAO, Boulder, and Kwajalein with multi-filter rotating shadowband radiometers (MFRSRs) and tracking sunphotometers. MFRSRs were first installed at Bermuda in February 1996, BAO in August 1996, Boulder David Skaggs Research Center (DSRC) laboratory in July 1999, and Kwajalein in April 1996. Data are downloaded by telephone and stored in the STAR data archive. With the intent of eventually replacing all MFRSRs with tracking sunphotometers, the MFRSRs at BAO and Kwajalein were removed in August 2000. Optical depth data analysis for all stations is performed routinely by first finding mornings and afternoons that produce acceptable Langley plots so that a time series of V_o values (instrument calibration constant) may be formed. This V_o time series is then smoothed, and a new V_o is calculated from the smoothed time series for every 1-min data point in the data set. These new V_o values along with the 1-min direct-beam irradiance data are used to calculate new total optical depth values. Finally, aerosol optical depth is calculated by subtracting other components of optical depth, such as that due to Rayleigh scattering, ozone absorption, and absorption by other gases.